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MODSAF WAS BUILT FOR TANK SIMULATION, AND THE MODELING ARCHITECTURE WAS BUILT ON THIS CONCEPT. THIS HAS RESULTED IN LOW-FIDELITY ROTARY WING MODEL BASED OFF OF A TANK MODEL, WHICH DOES NOT EFFECTIVELY PORTRAY RWA TO THE LEVEL NEEDED BY MOST MODSAF USERS. THIS EFFORT CONCENTRATES ON BUILDING A NEW RWA MODEL THAT CONTAINS AUTOMATED SIMULATION OF ARMY AVIATION TACTICS. THESE TACTICS ARE IN ACCORDANCE WITH SYSTEM CAPABILITIES DESCRIBED IN THE AVIATION FLIGHT MANUALS FOR AH-64, AH-64D, AH-64D LONGBOW, CH-47D, OH-58D, RAH-66, AND THE UH-60L.

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ADVANCED DISTRIBUTED SIMULATION TECHNOLOGY II (ADST II)

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CONCEPTUAL MODEL FOR RWA Enhancements

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MODSAF RWA Modeling and Behavior

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Related Conceptual Models	N/A
Author	LMC/SAIC

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3. System Requirements

Referenced ModSAF System Requirements
ModSAF tex.info

4. Overview

ModSAF was built for tank simulation, and the modeling architecture was built on this concept. This has resulted in low-fidelity rotary wing model based off of a tank model, which does not effectively portray RWA to the level needed by most ModSAF users. This effort concentrates on building a new RWA model that contains automated simulation of Army Aviation tactics. These tactics are in accordance with system capabilities described in the aviation flight manuals for AH-64, AH-64D, AH-64D Longbow, CH-47D, OH-58D, RAH-66, and the UH-60L.

This effort will be developed in accordance with the ModSAF Software Development Plan. The effort will be conducted using an Integrated Product Team approach, led by Ms. Susan Rodio. There is a dedicated cadre of engineers that will work the RWA development effort. This team is led by Mr. Dave Stober and is comprised of Mr. Gene Lonnon, Mr. Mark Varvak and Mr. Alex Portalatin. The core team will be supplemented with consultation from Mr. Anthony Courtemanche and Mr. Jon Williams as well as Subject Matter Experts from the Aviation Test Bed at Fort Rucker. In the initial stages of development, the ModSAF Integrated Product Team (IPT) conducted various analyses and studies in the investigation and refinement of the requirements. As System Requirements became more defined, the Verification and Validation (V&V) plan will be developed. Once sufficient knowledge is acquired (from published materials and Subject Matter Experts (SME)) about the domain, the Physical and Behavior Model Description will be produced. Based on the conclusions reached from the Knowledge Engineering process, Software Requirements Specification for Conceptual Model will be developed and delivered. SME concurrence will be reached iteratively in the development process and especially at key milestones.

Once the Software Requirements have been specified, the RWA Software Design Document and the Software Test Description will be produced and delivered.

Once the RWA software testing is complete, the ModSAF Software Version Release Document will be updated with the relevant information as it pertains to RWAD.

5. Document References

5.1 Government

- ADST II Statement of Work for the ModSAF Program, dated 22 July 1996.
- ADST II Preliminary Statement of Work (PSOW) for ModSAF Aviation Development, dated 15 August 1997
- AVTCOM, Aeronautical Design Standard (ADS) 33D - Handling Qualities Requirements for Military Rotorcraft, US Army AVTCOM, 1996
- FM 1-112, Attack Helicopter Operations, Headquarters Department of the Army, 1997
- FM 1-100, Introduction to Army Aviation, Headquarters Department of the Army, 1997
- TM 1-1520-238-10, Technical Manual Operator's Manual for Helicopter, Attack, AH-64A Apache, Headquarters, Department of the Army, 1994
- TM 1-1520-237-10, Technical Manual Operator's Manual for Army Models, UH-60A Helicopters, UH-60L Helicopters, EH-60A Helicopters, Headquarters, Department of the Army, 1996
- TM 55-1520-240-10, Technical Manual Operator's Manual for Army CH-47D Helicopter (EIC: RCD) Headquarters, Department of the Army, 1992
- TM 55-1520-248-10, Technical Manual Operator's Manual for Army OH-58D Helicopter Headquarters, Department of the Army, 1992
- SME support provided by the following: Jim Delashaw (PEO AVN/DOTDS), George Danek (US Army AFDD), Roy Schandorf (CATI/CSRDF), ROSS Hittpot (US Army WFD), Hal Ridley (ETRoop Camanche TSM).

5.2 Non-Government

- Software Development Plan (SDP) for the ModSAF Program, Rev C, dated 5 August 1997
- ModSAF Configuration Management Plan, Rev 5.2, dated 26 June 1997

1. Unit or Entities

The RWA effort shall develop realistic physical representations of the AH-64, AH-64D, AH-64D Longbow, CH-47D, OH-58D, RAH-66, and the UH-60L.

2. Task To Be Simulated

This effort will enhance the existing suite of RWA behaviors and control mechanisms to support the aviation missions of Attack and Reconnaissance. Existing behaviors enhancements will include introducing behaviors queering visual, atmospheric, and terrain information and to incorporate this information in pilot decisions. The effort will enhance RWA behaviors to query the flight model for performance capabilities and limitations and to incorporate in pilot decisions. Finally development of behaviors conducting Sector, Route and Zone Reconnaissance missions as conducted by Armored Cavalry organizations according to FM 1-112.

The relevant tasks to be simulated consist of:

1. Enhance Hover behavior
2. Fly route Enhancement
3. FARP specification optional and automatic
4. Change setup on start of Bounding Overwatch
5. Enhance landing
6. Enhance Assemble to use formations
7. Attack communication and use of laser designation
8. Create reconnaissance mission
9. Longbow System enabling
10. Implementing Improved Data Model (IDM) in Longbow Systems
11. Implementing Multi-weapon capability

1. Scenario/Story Board

Requirement definitions will be accomplished by the detailed analysis of the capabilities of the Rotary Wing Attack helicopters (AH-64A, AH-64D, AH-64 Longbow, OH-58D and RAH-66) and Operative Helicopters (UH-60L and CH-47D). This analysis will include:

1. Comparison between the plot of the proposed ModSAF RWA models dynamic performance (as computed) to the charts provided in the Technical Manual - Operator's Manuals (-10s).
2. Gather feedback from STRICOM designated SMEs on the user interface requirements to provide input fields for parameters as specified in the following groups:

   A. Airframe Performance from Atmospheric Wind. The airframe model will query ModSAF weather facilities for current wind speed and direction and update the airframe position and orientation to accurately reflect course and ground speed. The crosswind component of the local wind velocity will be included in airframe anti-torque poser requirements for hover.

B. Airframe Performance for Atmospheric Density. The airframe model will query the ModSAF weather model for temperature and pressure altitude and calculate density altitude to be used in modeling aircraft takeoff and hover performance.

C. Airframe Performance speeds will be found from the best rate of climb, best angle of climb and maximum forward speed will be accurately modeled. Ground effect will also be included in hover and takeoff performance.

D. Airframe Performance will use payload, which is found from personnel, fuel, weapons, the weight of sling load, external stores and other mission equipment will be included in the aircraft gross weight for purposes of performance modeling. Gross weight will change dynamically with fuel consumption, weapons discharge, and ingress/egress of personnel. Weight & balance will be required to be within accepted ranges.

E. Slope landing limitations will be available to behaviors for use in evaluating landing locations.

Dynamics

This effort will consist of the analysis, design, development and unit test of the Pilot subsystem for ModSAF RWA dynamics. There will be sufficient Domain and Fidelity analyses conducted to yield the determination of the appropriate level of control to be exerted by this semi-automated pilot. As in the performance of previous tasks, SME concurrence will be reached at key intervals in all phases. The new pilot library will handle the "gray" areas between the physical model and behaviors that currently exist in ModSAF. It will also simulate the human pilot in determining (as a function of terrain reasoning, way point objectives and current values of dynamics' variables) the control parameters: collective pitch, cyclic pitch, and directional pedals.

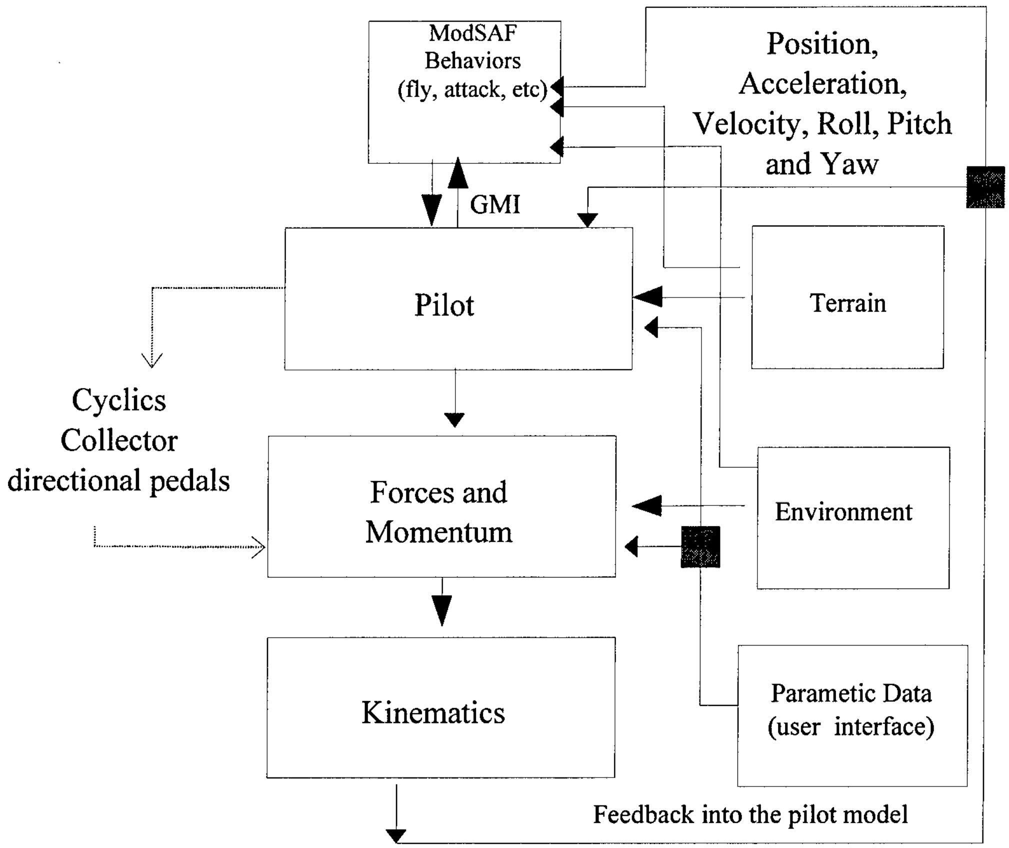

Figure 1

The Pilot design includes some behaviors or dynamics that are linked to the Pilot. This allows high fidelity behaviors without increasing the GMI interface or burdening behavior writers with complex details. For instance, handling take-off and landing in the Pilot Subsystem allows the simulation of the limitations of ground effect without using valuable CPU resources.

The Controls Subsystem will receive goals and objectives from the behaviors through the GMI and make adjustments due to terrain reasoning to determine the current goals of the helicopter. The Pilot model will take these goals (position, velocity, acceleration, pitch, yaw, and roll) or 6 degrees of freedom and compare them to current variables coming from the dynamic model to create a "difference" which will be used to set the cyclic and collective pitch, tail rotor thrust and engine power. This provides a closed loop system for control, which in addition to being a more general control system accommodates the slow tick rate in ModSAF. The team will investigate solutions to a possible problem where ModSAF is unable to tick the Control Subsystem at the rate required. One method may be breaking up long ticks by computing or estimating past results when slow ticks result. Then the Control Subsystem will take the result nearest the goal and avoid large overshoot.

The ModSAF RWA currently has three degrees of freedom, which are X, Y, and Z coordinates. The proposed model has enhanced degrees of freedom for RWA model including roll, pitch, and yaw, with respect to X, Y, and Z. Figure 4 is a diagram of the proposed dynamic model. The proposed dynamic model represents RWA as a flying dynamic object with six degrees freedom.

Flight Control System

Helicopter control requires the ability to produce moments and forces on the vehicle for two purposes: first, to produce equilibrium and thereby hold the helicopter in a desired trim state; and secondly, to produce accelerations and thereby change the helicopter velocity, position, and orientation. The helicopter control is accomplished primarily by producing moments about all three aircraft axes: pitch, roll, and yaw. The engine power is controlled with the throttle. The helicopter has in addition, direct control over the vertical force on the aircraft, corresponding to its vertical takeoff and landing capability. This additional control variable is part of the versatility of the helicopter. Usually the control task is eased by the use of a rotor speed governor on the engine throttle to automatically manage the power.

The main rotor motivates all but yaw control on the conventional helicopter and before the fuselage can respond, the rotor must respond. In many respects, the rotor acts like an actuator in the control circuit. Instantaneous response to the change of the main rotor controlling parameters is assumed. The rotor controls consist of cyclic and collective pitch. A collective pitch change gives a change in the mean blade angle of attack, which produces a change in the thrust magnitude. Cyclic pitch control gives a 1/rev-pitch motion in the rotating frame, which produces a tip-path-plane tilt. The thrust vector tilts with tip-path-plane, producing a moment about the helicopter center of gravity below the rotor hub. Thus, the command to the rotor collective and cyclic pitch gives efficient control over the magnitude and direction of the rotor thrust vector. When the rotor is operated at constant speed, then the blade pitch bearings and collective pitch control are required in any case for thrust management. The pilot's controls for the helicopter consist of a cyclic stick for control of longitudinal and lateral moments; a collective stick for control vertical force; foot pedals for control of yaw moment; and a throttle for control of the rotor speed and torque (power management).

In forward flight, the collective control is used mainly for thrust trim. Since the rotor power required varies with both thrust and forward speed, it is necessary to coordinate the throttle with collective and cyclic stick motions. A speed engine governor controls the power management automatically and maintains the rotor speed at the proper value. The helicopter is characterized with considerable coupling between controls. The manner in which the pilot's cyclic and collective control sticks are connected to the cyclic and collective pitch of each rotor depends on the helicopter configuration.

The connection of the pilot's controls to the rotor can be done in two ways: by a direct mechanical linkage (for example in the case of small helicopters), or second, electro-hydraulic actuators produce or augment the rotor control inputs commanded by displacements of the pilot's sticks. The proposed single rotor RWA model will be configured with one main rotor and one tail rotor (the duel rotor system, which is used by the CH-47, will be an enhancement of the single rotor model). Pitch moment is controlled by main rotor longitudinal cyclic control; roll moment is controlled by main rotor lateral cyclic control; vertical force is controlled by main rotor collective control; yaw moment is controlled by tail rotor collective control. The control positions determine state of the helicopter as a dynamic system i. e

x , y , z , p , q , r ,
$\dot{x}$, $\dot{y}$, $\dot{z}$, $\dot{p}$, $\dot{q}$, $\dot{r}$

Where x, y, z characterize a body position, p, q, r characterize a body orientation, and dotted parameters characterize rates of changes. The forces, which are exerted on the helicopter must be in stable equilibrium and subordinate to the pilot's controls. The situations where power required for flight is equal to admissible power available can cause uncontrolled flight and as a consequence of that instability of the dynamic system, which represents the helicopter. Thus, the stall effect on the main rotor blades can be considered as a sort of flutter, causing non-stable uncontrolled forward flight. In the same manner we consider the situations with exhausting flying capabilities of the helicopter, and these situations must be avoided by Automatic Flight Control System (AFCS).

Levels of Control System

The flight control system includes the pilot controls, mechanical linkages, actuation system and control rods. The flight control system includes augmentation through feedback control and hence will, in general, encompass the sensors, computing element any additional actuation in parallel and /or series with those driven by the mechanical inputs from the pilot. Controlling elements in the cockpit are the cyclic stick, the collective stick and the pedals. The Automatic Flight Control System (AFCS) is usually made up of Stability and Control Augmentation System (SCAS) functions applied through series actuators, and autopilot functions applied through parallel actuators.

First consider pitch and roll control, which are actuating through the swash plate mechanic system. Roll and pitch are coupled with some degree of mixing of inputs from pitch and roll cyclic stick; the mixing depends on different flying conditions. Roll and pitch controls are powered by hydraulic actuation, which is itself very complicated mechanism with its own feedback control designed to ensure that the response and stability to control inputs have good performance and stability characteristics. At the stick itself, an artificial feel system is usually incorporated to provide the pilot with stick centering tactile cues.

The pilot and the auto-stabilizer to the yaw actuator servo command yaw control. Functional connection between input and output depends on the geometry of mechanical link between cockpit control and tail rotor feathering.

Heave control is commanded by the main rotor collective pitch and achieved through raising and lowering the swash plate. Although many helicopters do not have collective acceleration control, but some of them as, for example Lynx, have one, which is fed back to the collective control causing an error discrepancy for further stabilization.

The flight control system in the real world reduces pilot workload by making the helicopter fly more like an ideal helicopter. The model of the flight control system will take out the idiosyncrasies of specific helicopters (mainly induced by the different aerodynamics of the hull for specific helicopters) making it possible to minimize helicopter specific modification for control inputs. Ideally, depending on the data for specific hulls and the sophistication of the FCS it may be possible to use a common autopilot and thus common control inputs for all types of helicopters.

Pilot Handling Qualities Ratings (HQR)

An aircraft model needs to be flight tested to assess its flying qualities in a range of Mission-Task-Elements (MTE) throughout its intended (OFE) Operational Flight Envelope. Control strategy may vary from pilot to pilot and that also affects on the performance of MTE. HQR measures precision hover, hovering turn, precision landing, pirouette, rapid bob-up/down, rapid sidestep, acceleration / deceleration, rapid slalom, pull-up/push hover, transient turn, roll reversals at load factors, deceleration to dash, evasive maneuver and (DVE) degraded visual environment maneuvers. Accordingly to ADS-33 there are standard requirements for the performance of MTE. Computerized model must be tested on MTE and compared with HQR.

Interface

A new interface connects the behaviors to the dynamic model. The dynamic model requires five control inputs, which will be generated, based on desired behavior, helicopter type and current state. Control inputs must be generated and used at a high frequency (up to 15 Hz). In order to not burden the interface and developer with this low-level detail, the pilot will generate the high frequency changes to FCS from the low frequency behavior inputs. Behaviors that use this model will input desired states in the form of primitives, which will be interpreted to goals, gain, and damping. The control input equation change to run the current control equations in the form of a generic command set that is interpreted into goals and control function parameters. A list of command set are started for each entity: the concept is similar to a "to do" list for each helicopter. This list is generated by the higher order primitives, which are called by the behaviors. The primitives called by the behaviors include Altitude, Heading, Velocity, Translation, Look at Point, Sidestep, Running Takeoff, Vertical Takeoff, Popup, Landing, Quick Stop, and Flyroute (which includes NOE, Contour and Low Level). The higher order primitives give the behavior writers added flexibility and simplicity.

Maneuvers

During the course of the Domain Analysis the team identified the source of and established traceability for the extensions to behavioral interfaces. The team created a chart presenting the relationship between the aviation missions and operations and the new primitive flight instructions to be added to the GMI. The source of this information was reviewed by SME interview and used published information revealing doctrinal and operational characteristics. A preliminary analysis yields the expectation that the GMI will add the following primitive flight instructions. The chart below shows the new RWA primitives across the top. Arguments for each primitive are shown vertically.

Altitude	Heading	Velocity	Translation	Look at Point
Desired End Altitude	Desired End Heading	Desired Speed	Point to Translate to	Point to Look At
Rate of Climb/Descent	Rate of Turn	Rate of Acceleration Used	Desired Speed	

Sidestep	Running Takeoff	Vertical Takeoff	Popup
Number of Movements From Left to Right	Takeoff Direction	Ending Direction	Mask Altitude
Time Before Movement Starts	Ending Direction	Ending Altitude	Unmask Altitude
	Ending Altitude	Rate of Altitude Climb	Mask Time
	Rate of altitude climb		Unmake Time
			Heading
			Number of Popups
			Rate of Altitude Change

Landing	Quickstop	Fly Route
Point to use for Approach	No Arguments	The Route to Follow
Point to use for Landing		Desired Velocity
Rate of Decent		Flight Mode: NOE, Contour, or Low Level
Heading		Rate of Acceleration Used
Clearance used to avoid trees, hill, etc.		Corridor Size (Used for NOE flight)
		Desired Altitude
		Number of Waypoints

Data Identification

The team has identified a set of physical model data that is need in order to model the helicopters accurately. The following lists the data is needed for each model.

1. General Geometrical and Physical Characteristics:

1. M - mass of the empty model (kg) -
2. I_x , I_y , I_z - moments of inertia (kgm^2)
3. R - main rotor radius (m)
4. R_t - tail rotor radius (m)
5. h - height of main rotor hub over center of gravity (m)
6. RPM - angular velocity of main rotor (rad /sec)
7. RPM_t - angular velocity of tail rotor (rad /sec)
8. L, W, H - overall dimensions: length, width, height (m)
9. N - number of blades for main rotor (quantity)
10. N_t - number of blades for tail rotor (quantity)
11. c - blade chord for main rotor (m)
12. c_t - blade chord for tail rotor (m)
13. l_{tr} - distance between axis of main rotor and tail rotor
14. A_b - area of main rotor blade (m2)
15. A_{bt} - area of tail rotor blade (m2)
16. main and tail rotors solidity (non - dim)
17. I_b - inertia of main rotor blade w. r. t. rotation axis (kgm2)

2. Aerodynamics Characteristics.

1. a - blade section lift-curve slope for main rotor (1/rad)
2. a_t - blade section lift-curve slope for tail rotor (1/rad)

3. T/A - equivalent disk loading main rotor (N/m^2)
4. T/A- equivalent disk loading tail rotor (N/m^2)
5. v_i - ideal induced velocity main rotor (m/sec)
6. v_i - ideal induced velocity tail rotor (m/sec)
7. T/P- hover efficiency (N/kW)
8. θ_{tw}- blade twist for main and tail rotor (rad)
9. c_l - section blades lift coefficient for main and tail rotors (non - dim)
10. c_d - section blades drag coefficients for main and tail rotors (non -dim)
11. Let α be an angle between fuselage and downwash including wind in longitudinal direction and β be an angle between fuselage and wind in lateral direction.
12. $C_{L(\alpha)}$ - lift coefficient due to alpha
13. $C_{D(\alpha)}$ - drag coefficient due to alpha
14. $C_M\theta$ - pitching moment coefficient due to alpha
15. $C_M\theta$ - pitching moment derivative due to the pitch rate
16. C_Y - side force coefficient due to the beta (Side Slip)
17. $C_M\psi$ - yawing moment coefficient due to the beta
18. $C_M\psi$ - yawing moment derivative due to the rate of yawing
19. $C_M\phi$ - rolling moment coefficient due to the beta
20. $C_M\phi$ - rolling moment derivative due to the rate of rolling

3. Engine Characteristics

1. P - total power on the turboshaft for main rotor (kW)
2. Q - torque moment on the shaft (kgm)
3. SFC - specific fuel consumption (kg/kW-hr)
4. P_t - maximal possible power on the tail rotor shaft (kW)
5. W_F - maximal fuel weight…

4. Control Characteristics

1. θ_0 - collective pitch range (deg)
2. θ_{1s} - longitudinal cyclic pitch range (deg)
3. θ_{1c} - lateral cyclic pitch range (deg)
4. θ_{0tr} - tail rotor collective pitch range (deg)
5. Maximal rates of changes for each control characteristic

5. Performance

1. Cruise speed as a function of ambient temperature and altitude (km/h)
2. V_{NE} - speed never exceed (km/h)…
3. V_c - vertical climb as a function of ambient temperature and altitude (m/sec)
4. H_{OGE} - hover ceiling as a function of ambient temperature
5. H_{IGE} - hover ceiling as a function of ambient temperature
6. Maximal rates of pitching, rolling and yawing
7. W - weights: empty, mission, gross and maximum ferry gross (N)
8. R - range of flight with the best horizontal velocity (km)
9. E - endurance of flight for longevity (loiter time) (hours)

10. The best angle of climb
11. The best horizontal speed

6. Mission load
1. Weight of munitions by categories: rockets, missiles, gun munitions

Fidelity Analysis

Fidelity is normally judged by comparison of test data collected on the computer model and the real physical model. The validation process can be described in terms of two kinds of fidelity - functional and physical, defined as follows. Physical fidelity is the level of fidelity when modeling physical phenomenon, in terms of their ability to represent the underlying physics, e.g. the rotor aerodynamic inflow and its compliance with the fluid mechanics.

Functional fidelity is the level of fidelity with respect to the overall model's ability to achieve compliance with some functional requirements, e.g. flying qualities: range of vertical and horizontal flight, endurance for some flying operations, and etc. It is useful to distinguish between these two approaches because they focus an attention on the two ends of the problem: modeling physics right and modeling flying capabilities correctly.

Physical Fidelity Analysis

In order to obtain the level of the fidelity required four factors should be modeled: general rotor/tail azimuth control, modeling a ridid body and moments of inertia, wind velocity which effect aerodynamic forces, and the effects of air density. Finally analysis includes the function aspects of the RWA model: limits on available power, forward flight, and altitude and analysis of range and endurance, performance, and takeoff capabilities.

Four modeling factors

1. Helicopter shall have one main rotor and one tail rotor for azimuth control. The tandem rotorcraft shall be constructed of this general model. is required further analyses and will be implemented in ModSAF on further stages of development.

2. RWA shall be model as a rigid body and will be considered as axis-symmetrical. The model will take into account a constant Ix, Iy, Iz moments of inertia.

3. Vector velocity of wind shall be used with coordinate u, v, and w with respect to the body axes. The model shall use air velocity to the aircraft given by coordinates: $\dot{x}, \dot{y}, \dot{z}$. Since actual wind vector velocity is given with respect to ground with coordinates: W_N, W_E, W_Z algorithms shall convert this vector to body axes coordinate system in order to get u, v, w. The differences $\dot{x} - u, \dot{y} - v, \dot{z} - w$ are used to calculate aerodynamic forces.

4. Air density ρ depends on the temperature and atmospheric pressure for specific geographic region and seasonal period. Since air density and atmospheric wind are included as calculated parameters into aerodynamic forces exerted on the aircraft, flying characteristics can be obtained such as: hover ceiling, rate of climb, maximal forward velocity, power required for specific maneuver as a function of

environmental arguments:

- MSL Altitude
- AGL Altitude
- Ambient Temperature
- Ambient Pressure
- Wind Speed
- Wind Direction

Limits on Available Power

Energy balance relation yields that the whole rotor spinning power dissipates on the power due to induced velocity, on the power due to profile, on the parasite drag power, power due to climb, and power due to losses in engine and transmission. In order properly calculate RWA performance, power losses due to gear train friction, cooling engine, driving the generator and driving the oil pump must be accounted. A frequent approach is to express these losses in terms of overall efficiency factor η. Typically main rotor losses range from 0.91 to 0.96. However the single main rotor helicopter must include the tail rotor power. The tail rotor calculation is complicated by the fact that the tail rotor operates in the wake of the main rotor and fuselage. The helicopter aerodynamic interference losses and tail rotor power can also be included in the efficiency factor η. The overall helicopters efficiency, including engine and transmission losses, aerodynamic interference, and tail rotor power, typically gives 0.80...0.87 for hover. The efficiency usually improves in forward flight, as the aerodynamic interference and tail rotor losses decrease. Thus, for each specific RWA η parameter will be implemented.

Limits on Forward Flight

RWA has limits on horizontal velocity due to stall effect on the rotor blades. The result of these limitations causes pure helicopter construction to achieve maximal speed between 150kts - 200kts and cannot ever exceed speeds of 200kts. In order to achieve a higher cruise speed it requires either improvement in rotor and fuselage aerodynamics or a significant change in the helicopter configuration. For each specific ModSAF RWA model such limitations will be implemented.

Limitations on Altitude

The absolute ceiling is defined as the altitude at which climb rate becomes zero. Usually we deal with service ceiling, which is defined as the altitude where the climb rate is reduced to some small, finite value (typically around .5 m/sec). The principal factors defining the ceiling are the reduction of engine power with increasing altitude (environmental effect), increase in power required as altitude grows (environmental effect), gross weight (constructive effect) and variation of the power required with speed (behavioral effect). Three altitude ceilings exist in helicopter flight. First, (OGE) Out-off-Ground-Effect ceiling is determined by the point, where power available equals power required with maximal loss of induced power, such that the ground can not decrease requirements for this part of power loss. Secondly, (IGE) In-Ground-Effect ceiling is determined by the point where influence of ground can substantially decrease induced power loss. Clearly, (IGE) ceiling is higher than (OGE) ceiling and they are both measured with respect to MSL (Mean Sea Level). The third ceiling of interest is the maximum ceiling, encountered in forward flight at the speed of minimum power required. The existence of such speed can be seen from functional dependence of power (P) vs. velocity (V). The projected RWA model will be tested for each specific helicopter, whose constructive characteristics are given by manufacturer. For example "Black Hawk" has OGE ceilings: 7,650ft for 95°F daytime; 9,375ft for $70°F, 11,125ft for standard day, 19,150ft for service ceiling.

Range and Endurance

The specific range and endurance are given as a function of Specific Fuel Consumption of the engine (SFC, in kg/hp-hr).

In general, specific range and endurance vary during a flight and (SFC) depends on the power and altitude, however, the range and the endurance may be approximately evaluated using specific range and specific endurance at the midpoint of the flight, where half of fuel consumed such that total weight is less by half of fuel consumed. The projected model will be tested for the range and the endurance for each helicopter and compared with manufacturer's data. Since gross weight effects the range and the endurance, the influence of change in payloads: (fuel, weapons, mission equipment, personnel) will be implemented in the RWA model. Similarly, RWA model will be tested for the range and the endurance under wind influence. One of the battle helicopter characteristics is loiter time, where a helicopter flies and observes targets or expects attack and fire commands.

It is very important, that the model endurance (in steady flight mode) meet military requirements for this primitive type of behavior. The RWA model will be tested to check this type of capability.

Performance

The speeds for best range and endurance may be found by examining specific range and endurance data as a function of velocity. Assuming that the specific fuel consumption is independent of velocity (which is not really true, because of dependence of the SFC on the engine power), the minimum fuel consumption per unit distance and hence the maximum range are achieved at the speed for minimum power over velocity. Similarly, the maximum endurance is achieved at the speed for minimum power. The RWA model will be tested to observe the best rate of climb and the best angle of climb.

Takeoffs

The RWA model must have capability for both types of takeoffs: Running Takeoff and Vertical Takeoff. Running takeoff is considered because it requires less power and allows the helicopter to hold a larger load. Usually RWA pilots execute a running takeoff when a vertical takeoff is not possible.

Behavior Development

In addition to drastically improving the fidelity of the rotary wing model, this effort enhances the existing suite of RWA behaviors and control mechanisms to support the aviation missions of Attack and Reconnaissance. Existing ModSAF RWA behaviors will be enhanced such that they may query visual, atmospheric, and terrain information to better model real pilot inputs. Additionally, this effort enhances RWA behaviors to query the flight model for performance capabilities, limitations and to incorporate in pilot decisions. Finally development of behaviors for conducting Sector, Route, and Zone Reconnaissance missions as conducted by Armored Cavalry organizations according to FM 1-112. Development of RWA behaviors is as follows:

1. Enhancement of RWA Hover will introduce a vertical/running takeoff decision. The behavior will make this decision by queering the model to determine if vertical takeoff is possible, and if not, the behavior will command a running takeoff. The model determines the possibility of vertical takeoff by factoring performance characteristics, payload, and atmospheric conditions.

2. RWA fly route will be enhanced to use velocity and height envelope limited by aircraft dynamics and further limited by atmospheric visibility degraded vision, environment and terrain. Rotor disks will specify formation spacing of the aircraft. (Rotor disk size will be provided by the model for that particular aircraft).

3. Bounding Overwatch enhancement will include choosing the light section based on less ammunition.

4. Enhancement of RWA Land will introduce vertical/running takeoff decision. This is similar to the query needed for RWA hover.

5. Enhancement to the RWA Assemble will add formations as used in RWA fly route, including a scatter formation. Formation spacing in the form of rotor disk will also be user input into this behavior.

6. Enhancement of RWA Attack will be enhanced to have the units pop up at the same time, so that the helicopters will attack the targets at the same time, thus using the element of surpass. Modifications will be made so that aircraft will communicate targets to engage, thus avoid multiple engagement on the same target. Also a criteria will be used so that laser designation will be executed appropriately in the attack mission.

7. A reconnaissance behavior will be developed in ModSAF. This behavior will allow the user to specify the type of mission (zone, area, or route). Scout helicopter(s) will perform a search movement task in accordance in FM-112 reconnaissance and security descriptions.

Identification of RWA behaviors tasks

Enhance Hover behavior: Enhancement of RWA Hover will introduce a vertical/running takeoff decision. The behavior will make this decision by querying the model to determine if vertical takeoff is possible, and if not, the behavior will command a running takeoff. The model determines the possibility of vertical takeoff by factoring performance characteristics, payload, and atmospheric conditions.

Fly route Enhancement: RWA fly route will be enhanced to use velocity and height envelope limited by aircraft dynamics and further limited by atmospheric visibility, degraded vision, environment and terrain. Rotor disks will specify formation spacing of the aircraft. (Rotor disk size will be provided by the model for that particular aircraft).

Make FARP specification optional and automatic: RWA FARP locations (which are currently required to be specified by the ModSAF user on every task) shall automatically use a predefined FARP the user has specified. Tasks will search in the PO database for a FARP that the helicopter unit may use. General rule is only one FARP is used for the whole battalion.

Change setup on start of Bounding Overwatch: Bounding Overwatch enhancement will include choosing the light section based on less ammunition.

Enhance landing: Enhancement of RWA Land will introduce vertical/running takeoff decision. This is similar to the query needed for RWA hover.

Enhance Assemble to use formations: Enhancement to the RWA Assemble will add formations as used in RWA fly route, including a scatter formation. Formation spacing in the form of rotor disk will also be user input into this behavior.

Attack communication and use of laser designation: Enhancement of RWA Attack will be enhanced to have the units pop up at the same time. So that the helicopters will attack the targets at the same time, thus using the element of surpass. Modifications will be made so that aircraft will communicate targets to engage, thus avoid multiple engagement on the same target. Also a criteria will be used so that laser designation will be executed appropriately in the attack mission.

Create reconnaissance mission: A reconnaissance behavior will be developed in ModSAF. This behavior will allow the user to specify the type of mission (zone, area, or route). Scout helicopter(s) will perform a search movement task and show a contact report in the message GUI window. Scouts should prevent from being discovered by the enemy and forcing a more abrupt action. If the enemy discovers element of the squadron first, those elements may be forced into a hasty defense while other assets develop the situation.

Longbow System enabling: An AH-64D equipped with Millimeter Wave (MMW) Fire Control Radar (FCR) is able to detect, classify (i.e., tracked, wheeled, air defense, hovering, flying), prioritize, and engage targets with radar frequency (RF) Hellfire Missiles without visually acquiring the target. Currently AH-64D must have a visual sighting to engage a target.

Implementing Improved Data Model (IDM) in Longbow Systems: This offers a backward compatibility to the OH-58D Airborne Target Handover System (which is used in laser designation). This system allows the RF Hellfire missiles to use target handover. Thus one AH-64D may identify a target location using the FCR and hand over the target location to another AH-64D.

Implementing Multi-weapon capability: Some of this capability is already in ModSAF. However it should be extended to allow rapid employment of all available weapons (Laser missiles, Air-To-Air missiles, Aerial Rocket System and the 30mm Cannon).

Behavior Data Identification

In identifying the data needed for each behavior, we can break down the high level behaviors into primitives, thus demonstrating that the fundamental maneuvers are complete in listing. The table below show the high level behavior in the left side with a break down into flight primitives moving to the right. Note that the primitives listed on the right may not be executed in the behavior, but must be listed as a possibility.

RWA Vehicle Occupy Area

PRIMITIVE: Altitude		
Will Use Unit REACTION if enemy detected, being fired upon	PRIMITIVE: Flyroute	PRIMITIVE: Helicopter Jinking
Will Use Unit RADAR_WARN if radar sensed	PRIMITIVE: Flyroute	PRIMITIVE: Sidestep
Unit Move to landing formation	PRIMITIVE: Altitude	PRIMITIVE: Translation
PRIMITIVE: Landing		

RWA Vehicle Depart Area		
PRIMITIVE: Vertical or Running Takeoff		
PRIMITIVE: Altitude		
Unit Move into flight formation	PRIMITIVE: Altitude	PRIMITIVE: Translation
Will Use Unit REACTION if enemy detected, being fired upon	PRIMITIVE: Flyroute	PRIMITIVE: Sidestep
Will Use Unit RADAR_WARN if radar sensed	PRIMITIVE: Flyroute	PRIMITIVE: Sidestep

RWA Vehicle Fly Route			
RWA Unit Fly Route	PRIMITIVE: Flyroute	* If Mode is NOE, use Sidestep and Quickstop	
Will Use Unit FARP if out of fuel, ammo	PRIMITIVE: Flyroute	PRIMITIVE: Landing	
Will Use Unit REACTION if enemy detected, being fired upon	PRIMITIVE: Flyroute (to avoid being detected)	PRIMITIVE: Sidestep (to avoid fire)	
Will Use Unit RADAR_WARN if radar sensed	PRIMITIVE: Flyroute (to avoid radar)		
PRIMITIVE: Altitude			
PRIMITIVE: Landing			

* Note: Since we are using NOE, the primitive Sidestep will be used to move around terrain obstricles and the primitive Quickstop may be used for an emergency stop to avoid running into an obstacle.

RWA Unit Attack	PREP: RWA Unit is in Assembly Area
RWA Unit Departure of Assembly Area	BEHAVIOR: RWA Vehicle Depart Area
RWA Unit Departure of Forward Assembly Area	BEHAVIOR: RWA Vehicle Depart Area
Fly along an Air Route	BEHAVIOR: RWA Vehicle Fly Route
Occupation of Holding Area, and refuel load ammo	BEHAVIOR: RWA Vehicle Occupy Area
Fly Attack Route	BEHAVIOR: RWA Vehicle Fly Route
Occupy Battle Positions	BEHAVIOR: RWA Vehicle Fly Route
	Occupy masked position
	Will Use FARP if condition exists
RWA Unit Fly Route back to Holding Area	BEHAVIOR: RWA Vehicle Fly Route

Occupy a Holding Area, and refuel	BEHAVIOR: RWA Vehicle Occupy Area
RWA Unit Fly Route back to Assembly Area	BEHAVIOR: RWA Vehicle Fly Route
Occupy Assembly Area	BEHAVIOR: RWA Vehicle Occupy Area

RWA Reconnaissance		
RWA Unit Departure of Area	BEHAVIOR: RWA Vehicle Depart Area	
Unit/vehicle Moves along Route	BEHAVIOR: RWA Vehicle Fly Route	
Unit/vehicle Sends Information back	Obtained information about an enemy force moving along the specific route	Determined trafficability of possible routes or lateral routes along the route
Unit/Vehicle Unloads cargo carried (if selected)	BEHAVIOR: RWA Vehicle Occupy Area {Fuel/Ammo}	Vehicle Unload Cargo
Unit Routing Back	BEHAVIOR: RWA Vehicle Fly Route	

Algorithm Methodology

Existing ModSAF algorithms will be used for physical model simulation, whereas new algorithms will be developed for tactical behaviors.

Testing Procedures

Based on the fidelity analyses the testing procedures will be developed to check flying qualities in accordance with manufacturer's performance data and handling qualities in accordance with ADS-33.

Data Availability

Additional sources of information, not yet obtained, are still needed for development of specific helicopter modeling based on the projected generic RWA model. It is necessary to obtain data for physical characteristics of military helicopters, for aerodynamic characteristics, and performance characteristics and their dependence from environmental parameters.

Other

N/A

Issues

N/A

Appendix A - WWW Document References

http://www.keystone-helicopter.com/

http://www.rotor.com/annual/menu.htm

http://www.rpi.edu/%7Eharkij/helicopter.html